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MODELLING AND OPTIMISATION OF TONGKAT ALI WATER EXTRACT PRODUCTION UTILISING A BATCH PROCESS SIMULATOR

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ABSTRACT

Eurycoma longifolia or Tongkat Ali water extract is a valued product in the phytochemical industry. This work features the modelling and optimisation of a Tongkat Ali water extract production using SuperPro Designer®, a batch process simulator. The objective of this work is to design an economically viable production scheme for a locally developed Tongkat Ali extract production process. The current pilot scale production scheme of Tongkat Ali extract was used to simulate the base case process. Four alternative production schemes were further developed with several debottlenecking and optimisation strategies. The final alternative scheme was reported to achieve a product yield of 3.00%, with an annual production of 1137.72 kg of Tongkat Ali extract. The minimum batch cycle time was reduced from 24.4 hours in the base case to 8.04 hours. Economic analysis determined that the proposed alternative production scheme has an annual revenue of $6.32M, with a 38.6% gross margin and a 32.9% return on investment.

Keywords: Phytochemical processing, herbal processing, process simulation and optimisation, batch processes, process debottlenecking.

I. INTRODUCTION

Eurycoma longifolia, more commonly known as Tongkat Ali, is a tropical herbal plant found in several parts of South East Asia such as Malaysia, Indonesia, and Vietnam. Locally it is also known as Payung Ali, Penawar Pahit, Setunjang Bumi, Bedara Pahit, Tongkat Baginda, Pokok Syurga, Tongkat Ali Hitam, Pokok Jelas and Jelaih. There are four different species of Tongkat Ali plant, namely *Eurycoma longifolia*, *Eurycoma apiculata*, *Polyathia bullata* and *Goniothalamus sp.* Among the four, *Eurycoma longifolia* is the most commonly used species for herbal extract production. This plant bears fruit after 2½ years of cultivation while the root is usually taken to be processed after 4 years of cultivation.

Traditionally, Tongkat Ali is used for its aphrodisiac, anti-pyretic and anti-malarial effects as well as a general tonic. A decoction of its long woody tap root is taken orally. The benefits of the roots of Tongkat Ali include restoring energy and vitality, enhancing blood flow and functioning as a herbal ingredient for women after child birth. The leaves cure malaria, ulcers, syphilis and gonorrhea, prevents gum diseases, and relieves insect bites.

The *herbal-based phytochemical* industry is a new and upcoming industrial sector in Malaysia. Common phytochemicals or herbal products in the market include Tongkat Ali, Misai Kucing (*Orthosiphon stamineus*) and Hempedu Bumi (*Andrographis paniculata*) extracts. Misai Kucing can be used for kidney related and joint ailments while Hempedu Bumi is used for its anti-diabetic and anti-hypertensive properties [1]. Due to the high market demand and their medicinal effects, these phytochemical products have a high commercial value in the local and global market [1]. For instance, Tongkat Ali water extract can be sold up to USD26 per bottle of 60 capsules, which is equivalent to USD8700/kg extract [2].

However, a common pitfall associated with this industrial sector is that, the production of these phytochemicals (such as Tongkat Ali water extract) is mainly carried out through various traditional methods (e.g. boiling or soaking) which often lead to high losses and low product yield. Hence much effort needs to be done to develop this "backyard" industry into an industrial sector. Often, various engineering contribution and practises are needed for this transformation. This includes the various stages of phytochemical processing, e.g. planting and harvesting, raw material preparation, processing as well as value added production [3]. Engineering practices such as processing (extraction) technology, process synthesis and optimisation, product formulation hence play important roles in ensuring the "modernisation" of phytochemical industry to be a success [3].

This work presents the use of a batch process simulator in modelling and optimising a locally developed process for Tongkat Ali water extract production. It aims to develop an economically viable production scheme via the use of computer aided process design (CAPD) and simulation tools. CAPD and simulation are important tools in the process industries since the late 1960's. It involves the use of computers to perform steady-state heat and mass balancing and sizing and costing calculations for a process [4]. However, this tool is still relatively new to the field of bio-related process engineering [5], such as that in the biochemical and phytochemical industries.

In this work, SuperPro Designer® v5.0, a commercial process simulation tool for batch process modelling and optimisation, is used to develop an economically viable scheme for the production of Tongkat Ali water extract. The base case simulation model is based on the current operating condition of a pilot scale production at Chemical Engineering Pilot Plant, Universiti Teknologi Malaysia (CEPP, UTM). To achieve industrial scale production, it is important to consider the various process and scheduling bottlenecks in the current production setup. Four alternative production schemes were further developed in the simulation model by incorporating various debottlenecking strategies to overcome the current process limitations. Value added steps were introduced to produce a final Tongkat Ali extract product of higher commercial value. Results reveal that the industrial scale production scheme is of good economic performance, with a return on investment (ROI) figure of 32.9% and a payback period of approximately three years.

II. PROCESS DESCRIPTION

Fig. 1 shows the process flow diagram of a pilot scale production of *Eurycoma longifolia* water extract at CEPP, UTM. The two main processing steps in this water extract production consists of the two stage counter-current solid-liquid extraction (leaching) process as well as the spray drying operation. The current process is operated at a batch throughput of 40 kg of ground Tongkat Ali root, which is supplied in chip form. The processing steps are explained in detail as follows.

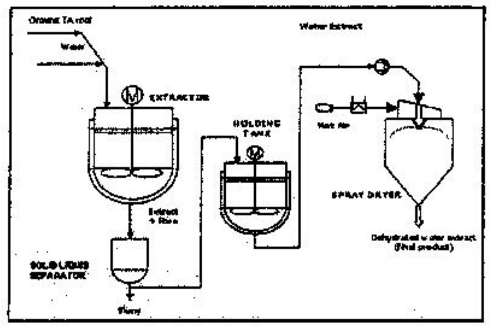

Fig. 1. Process flow diagram of pilot scale *Eurycoma longifolia* water extract production

In the first operating step, i.e. the two stage counter-current solid-liquid extraction process, fresh ground Tongkat Ali root chips are sent to the extraction vessel to be extracted using the solvent of boiled water. The ratio of water volume to the root chips weight is maintained at 6 L: 1 kg. In the first stage of extraction, Tongkat Ali roots are boiled with fresh water (or recycled water for the second batch and above) at a temperature range of 110 to 120°C. This boiling operation is maintained for two hours to provide sufficient time for the phytochemicals in the root chips to be leached into the extraction solvent (water).

Upon the completion of the first stage of extraction, the extracted liquid is pumped and stored in a holding tank, to be later sent for spray drying. The leftover chips are then extracted using fresh solvent in the second stage of extraction, following the same operating conditions as the first extraction stage. Upon the completion of the second stage extraction, the solvent is removed and stored for reuse in the following batch; and the leftover chips are discharged. Approximately 35% of the solvent (water) is trapped in the discharged chips and are taken as process losses.

The extract from the first extraction stage is sent to the spray dryer operated at 170°C to produce Tongkat Ali extract powder. Due to the limitation of the spray drier capacity (a feed rate of 7 L/hr of spray liquid), the drying operation takes approximately 22 hours to complete. Spray drying is widely used in most herbal-based phytochemical processing to produce extract powders, mainly due to its relatively shorter process time and lower process economics, as compared to other product drying techniques such as freeze drying. In the current production scheme, the spray dried extract powder is sold as the final product in bulk form.

In this pilot scale production, the overall process yield of Tongkat Ali extract is estimated at 3.0 wt%. A detailed simulation has been performed to model the production and to assess the annual process throughput as well as its economic performance, as described in the following section.

III. BASE CASE PROCESS SIMULATION

In the development of base case simulation model (Fig. 2), user-defined components were approximated due to the absence of Tongkat Ali substances in the simulator component database. This includes the Tongkat Ali root chips, fibre, residue and extract. Due to the nature of the process that is operated in batch mode, the base case simulation model was developed to reflect the actual operating condition of the process. This involved the modelling of a few *operations* that take place sequentially in a single *unit procedure*. For instance, vessel procedure P-1 in Fig. 2 was used to model the first stage of extraction process that consist of sequential operations of raw material charges, material heating, extraction process as well as product discharge. All these individual operations took place in the single vessel of V-101. The modelling of these single operations is described next.

The first operation in P-1 involves the charging of the raw material, i.e. 40 kg of ground Tongkat Ali root chips (denoted as "TA root" in Fig. 2) into the extraction vessel. Extraction solvent charging is the next subsequent operation in the procedure. As mentioned earlier, the solvent for the first extraction stage mainly consists of the recycle water (denoted as "R.water") from the second stage of the extraction process. After the transferring of recycle water has taken place, 30 L of fresh water is next charged into P-1 as solvent make-up, to supplement the losses of recycle water in the solid residue from the extraction process.

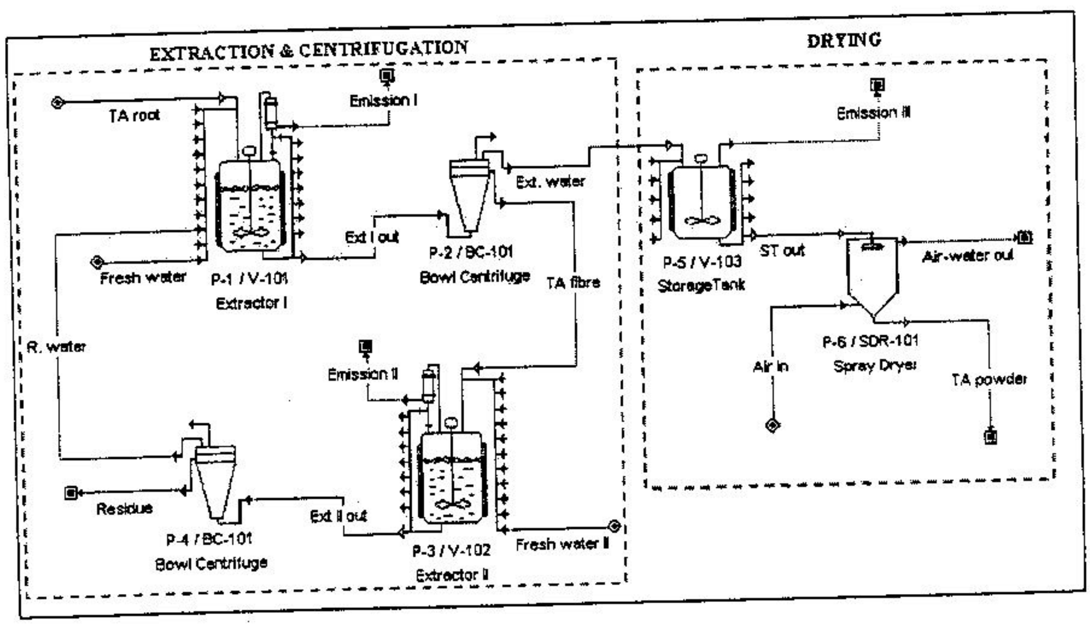

Fig. 2. Simulation flowsheet for base case process

The operation that follows is the heating of solvent-root mixture from room temperature to 110°C. The extraction process is assumed to take place at the beginning of the heating operation. The extraction vessel is maintained at 110°C for two hours. Based on the product yield of 3.0 wt% in the pilot scale operation, Tongkat Ali extract produced in the extraction vessel was determined as 1.2 kg per batch of extraction operation.

Upon the completion of the extraction process, the resulting extract-water and solid mixture is sent to the centrifugation procedure P-2, that took place in the Bowl Centrifuge BC-101. This procedure is chosen to model the removal of solids content (the leftover fibre) from the effluent of extraction vessel V-101. The centrifugation procedure is used to model the siphon system which is implemented in the current pilot plant production scheme. 100% removal is set for the Tongkat Ali fibre (denoted as "TA fibre"); while 35% removal for extract-water mixture in the centrifugation procedure to represent the product losses. The remaining extract-water mixture (denoted as "Ext. water") is transferred to be temporarily stored in the storage procedure P-5 (in vessel V-103).

The separated solids from P-2 are transferred into vessel procedure P-3 (in V-102) to undergo the second stage of the extraction process. The operating condition for the second stage of the extraction process is the same with that in the first stage in procedure P-1. Note that due to the counter-current mode of extraction process, 240 L of fresh water is fed at this second stage of extraction process. Product yield at this stage is assumed at 1%. The effluent from vessel procedure P-3 is separated by the centrifugation procedure P-4, which utilises the same equipment of BC-101 in procedure P-2. The extract water leaving P-4 is recycled to P-1 while the solid content leaves as process residue. The operating parameter for this procedure is also set to be the same with that in procedure P-2.

Upon the completion of extract mixture transfer-in operation of P-5, the stored extract-water mixture is sent to the spray drying procedure (P-6/SDR-101) at a flowrate of 0.12 L/min. Ambient air is heated to 170°C before it is fed into SDR-101 as the drying medium. Hot air and evaporated water vapour is emitted from the top stream of SDR-101 at 105°C while TA powder leaves at the bottom stream at 70°C. It is assumed that 1% of the Tongkat Ali extract is lost together with the emitted air.

Table 2 shows the preliminary evaluation on process throughput and economics performance of the base case simulation model. As shown, this model reports a product yield of 3.02%, with the batch throughput of 1.21 kg Tongkat Ali extracts. Based on the annual operating time of 7920 hr and minimum cycle time of 30.44 hr, the annual production for the process model is calculated as 323 batches. This corresponds to 390.73 kg of Tongkat Ali extract produced per annum. In the long run, this production rate will not be sufficient to fulfil the market needs as Tongkat Ali extract demand is predicted to reach at least 250% of the current production rate.

	Process parameters	Value
Throughput	Annual throughput (kg /yr)	390.73
	Batch throughput (kg/batch)	1.21
	Yield (%/batch)	3.02
	Minimum cycle time (hr)	24.44
	Plant batch time (hr)	30.44
	Number of batches per year	323
Economics	Capital cost ($)	3,030,935
	Operating cost ($/yr)	2,000,512
	Gross margin (%)	-675.74
	ROI (%)	-48.80
	Total revenues($/yr)	257,883

Table 1. Throughput and economic analysis results for the base case simulation

On the other hand, preliminary economic analysis conducted on the base case model reveals that the current production scheme has relatively high capital (assuming that all process equipment are newly purchased) and operating cost as compared to its annual revenue. Negative values are reported in both gross margin and return on investment (ROI) of the model. Hence, efforts are needed to improve the economic performance of the production scheme for a more economic viable production.

As the manufacturing process is carried out in batch operation, efforts have been made to document the scheduling details of each processing steps. This includes the *setup time*, *process time*, and *start time* of each individual operation in each unit procedure. The details of this scheduling summary are shown in Table 2.

Procedure	Operation	ST	PT	Start time
P-1/V-101	CHARGE-TA	10 mins	16 mins	beginning of batch
	TRANS-IN-R.H2O	10 mins	2 hrs	after CHARGE-1
	CHARGE-H2O	10 mins	6.25 mins	after TRANSFER-IN-1
	HEAT-1	5 mins	30 mins	after CHARGE-2
	EXTRACT-1	-	2hrs	after HEAT-1
	TRANS-OUT-1	10 mins	2 hrs	after EXTRACT-1
P-2/BC-101	CENTRIFUGE-1	10 mins	2 hrs	starts with TRANS-OUT-1 in P-1
P-3/V-102	TRANS-IN-TA-FIBRE	10 mins	2 hrs	starts with CENTRIFUGE-1 in P-2
	CHARGE-H2O	10 mins	50 mins	after TRANSFER-IN-1
	HEAT-1	5 mins	30 mins	after CHARGE-1
	EXTRACT-1	-	2hrs	after HEAT-1
	TRANS-OUT-1	10 mins	2 hrs	after EXTRACT-1
P-4/BC-101	CENTRIFUGE-1	10 mins	2 hrs	starts with TRANS-OUT-1 in P-2
P-5/V-103	TRANS-IN-1	10 mins	2 hrs	starts with CENTRIFUGE -1 in P-2
	STORE-1	-	2 hrs	starts with TRANS-IN-1
	TRANS-OUT-1	20 mins	22.11 hrs	after STORE-1
P-6/SDR-101	DRY-1	20 mins	22.11 hrs	starts with TRANS-OUT-1
	CIP-1		15 mins	after DRY-1

Note: ST = setup time, PT = process time

Table 2. Scheduling summary for the base case model

IV. BOTTLENECK IDENTIFICATION STRATEGIES

In order to increase the process throughput, one will have to identify the process bottleneck that limits the current production. Bottlenecks are process limitations that are related to either equipment or resource such as demand for various utilities, labour, raw material, etc. In batch manufacturing, two types of process bottlenecks can be identified, i.e. size bottleneck and scheduling bottleneck.

Similarly, for batch processes, equipment utilisation can be measured through its *capacity utilisation* and *equipment uptime* [6, 7]. Capacity utilisation is defined as the fraction of equipment's capacity used during an operation while equipment uptime is the measure of how effective a piece of equipment is utilised in time. The product of equipment capacity utilisation and its uptime defines the *combined utilisation* of the respective equipment. This measures how certain equipment utilised its capacity (size) and uptime [7]. The processing step with the highest combined utilisation is always identified as the process bottleneck.

Fig. 3 shows the Throughput Analysis Chart that displays capacity utilisation, equipment uptime and combined utilisation for each procedure. As shown, the spray drying procedure (P-6/SDR-101) is identified as the process bottleneck due to its highest combined utilisation. The capacity utilisation of this procedure has reached its maximum of 100% (due to the limitation of its feed flowrate of 0.12 L/min); while its equipment uptime is relatively high (drying operation duration of 22.11 hrs, Table 2). Also, P-6 can be classified as the process scheduling bottleneck which limits the annual production of 323 batches per year. Hence, in order to increase the annual production, debottlenecking strategies should focus on the reduction of the drying operation time, which will enable higher batches to be produced annually.

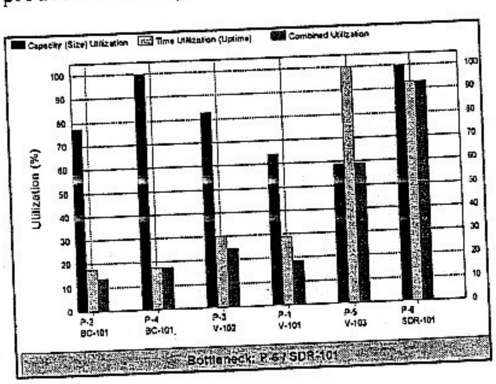

Fig. 3. Throughput Analysis Chart

V. DEBOTTLENECKING SCHEMES

The previous section determined that the current production of Tongkat Ali extract powder is economically infeasible due to the low revenue generated by the low annual production rate. However, efforts to increase production were limited by the process scheduling bottleneck, i.e. spray drying operation. Three debottlenecking schemes were initially developed based on the base case simulation. These schemes were analysed to evaluate their probability to increase the plant annual production. Economic evaluation was also performed to evaluate all debottlenecking schemes to identify the most economically attractive option.

5.1 Alternative production schemes

In Scheme 1, a new spray dryer was added in parallel with the existing spray dryer to reduce the process time for drying operation into half. The process time of spray drying operation was reduced significantly from 22.11 hours to 11.05 hours while other equipment and scheduling setup remain unchanged.

Scheme 2 adds a new double effect forward feed evaporator to concentrate the extract prior to the spray dryer. Due to the reduction of volume in the Tongkat Ali water extract, the process time for the spray drying operation was significantly reduced from 22.11 hours to 11.05 hours.

Scheme 3 combines the strategies in the previous two schemes. The process time of spray drying operation has been reduced significantly from 22.11 hours to 5.17 hours. Table 3 shows the process throughput and economics summary of the base case and the debottlenecking schemes.

All the proposed debottlenecking schemes demonstrate significant improvement on the annual throughput. This is mainly due to the reduction of minimum cycle time associated with spray drying procedures. Note that Scheme 2 and Scheme 3 exhibit lower value of overall product yield due to additional losses in the evaporator (P-7 in Figure 4). Among all schemes, Scheme 3 has the highest annual process throughput and hence identified as the debottlenecking strategy.

5.2 Economic optimisation scheme

However, economic analysis of the production schemes reveals that the proposed schemes are still economically infeasible although the annual throughput has been increased. All proposed schemes have seen an increase in capital and operating costs due to addition of new equipments. As shown in Table 3, the operating cost for all the debottlenecking schemes are higher than the total revenues. This leads to the negative ROI values and hence, payback period for all schemes is unachievable. The main reason for this defect is the low revenue of the process.

Therefore, in the final scheme proposed, Scheme 4, alternatives to produce more value added product are implemented. Attention is given on efforts to reduce process operating cost and to add value to the final product.

The first effort in Scheme 4 as shown in Figure 4 is to reduce the raw material cost of the process by adding a new grinder (P-1/GR10). Raw material in the base case simulation is taken as the ground Tongkat Ali chips with a cost of $ 6.50/kg. With the addition of a grinder, the raw material can be substituted with fresh Tongkat Ali roots which cost $ 3.20/kg, approximately half of the original cost.

Next, effort is made to improve the process economics by producing a value-added final product. In all previous proposed schemes, the final product of Tongkat Ali extract powder is sold at a price of $ 655/kg. An alternative to produce a higher value-added product is the Tongkat Ali extract capsules which are sold at a price of $ 26 per bottle of 60 capsules, which is equivalent to about $ 8700/kg Tongkat Ali extract. To produce Tongkat Ali extract capsules, new equipment are needed. This includes the mixing (P-11/MX-101), mixture preparing (P-12/MX-102), capsuling (P-13/TB-101), bottling (P-14/BX-101) and packaging (P-15/BX-102) procedures.

The Tongkat Ali extract powder from the spray driers is mixed with Maltodextrin in procedure P-12 (MX-102) at a ratio of 1 kg extract: 8 kg Maltodextrin. The extract-Maltodextrin mixture is fed into a capsuling machine (P-13/TB-101) where the mixture is capsuled at a rate of 50 capsules/min containing 450 mg each. Once the capsuling operation starts in P-13, the capsules produced are fed into bottling machine

(P-14/BX-101) where they are filled in plastic bottles at a rate of 60 capsules/bottle. When this operation is over, the filled bottles are sent to packaging (P-15/BX-102) where the bottles are packed in boxes with each box containing 12 bottles of Tongkat Ali extract capsules.

Table 3 shows that the process throughput of Scheme 4 has decreased due to the decrease in number of batches per year. This is mainly due to the installation of several new equipments resulting in longer batch cycle time. This is illustrated in the Operation Gantt Chart for Scheme 4 as shown in Fig. 5.

The main product of the process is no longer Tongkat Ali extract powder but extract capsules. Also, as shown in Table 3, the total capital and operating cost has increased in Scheme 4 due to the installation of new equipment. However, this increase is justified by a drastic increase in the process revenues. This fulfils the objective to increase the total revenues with higher margin. As a result of the increase in revenues the gross margin and ROI have improved significantly.

In the previous schemes, calculations show that the capital investment was not recoverable since the operating cost was exceeding the total revenues. If this scheme is implemented the capital investment can be recovered in 3.04 years with a ROI of 32.94 %.

	Process parameters	Base case	Scheme 1	Scheme 2	Scheme 3	Scheme 4
Throughput	Batch throughput (kg)	1.21	1.21	1.20	1.20	1.20
	Overall product yield (%)	3.02	3.02	3.00	3.00	3.00
	Minimum cycle time (hr)	24.44	13.39	13.55	8.04	8.32
	Plant batch time (hr)	30.44	18.5	18.67	13.16	24.42
	Number of batches per year	323	591	583	984	950
	Annual throughput (kg/yr)	390.73	714.93	698.20	1178.44	1137.72
Economics	Capital cost ($)	3030935	4779605	3617011	5373844	6034342
	Operating cost ($/yr)	2000512	2794034	2742090	3631921	3883660
	Total revenues ($/yr)	257883	471854	460812	777769	6320667
	Gross margin (%)	-675.74	-492.14	-495.06	-366.97	38.56
	ROI (%)	-48.80	-39.84	-54.45	-44.43	32.94

Table 3. Throughput and economic analysis results

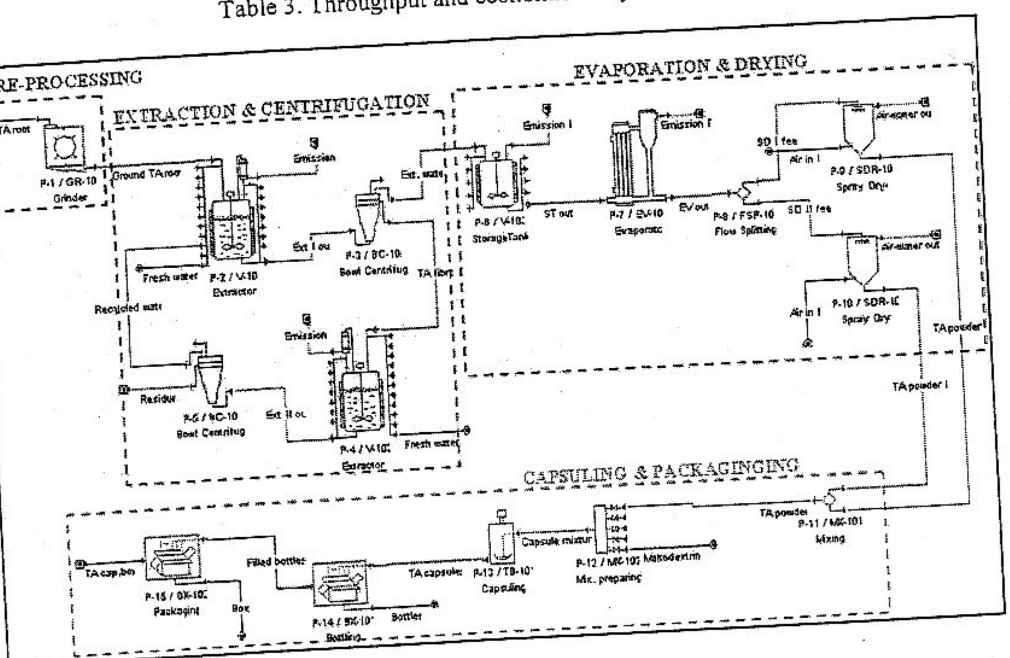

Fig 4. Simulation flowsheet of Scheme 4

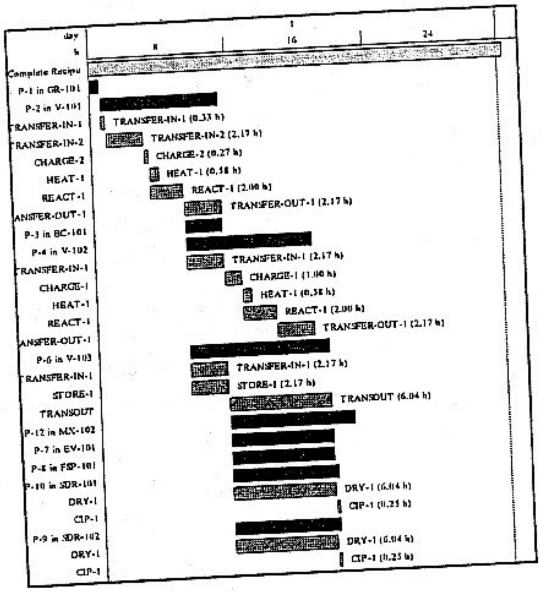

Fig. 5. Operations Gantt Chart of Scheme 4

VI. CONCLUSION

Tongkat Ali extract production is modelled and optimised in this work, based on an existing manufacturing setup in Chemical Engineering Pilot Plant, Universiti Teknologi Malaysia. The base case process is analysed and the spray drying section is identified as the overall process bottleneck. Three debottlenecking schemes are proposed and analysed through simulation. The debottlenecking scheme with the highest throughput that fulfils the customers' need is further analysed to access its economic performance. Due to the unattractive economic performance, a grinder and a new capsuling and packaging line is proposed to add value to the final product in Scheme 4. The modification yields an annual revenue of $ 6,320,667 with a gross margin of 38.56%, return on investment of 32.94% and a payback period of 3.04 years.

VII. ACKNOWLEDGEMENT

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